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13. ABSTRACT (Maximum 200 words)

In this research project, we have made significant progress in several fronts of modern control technology. Our major research results include: new model identification and validation techniques, new model uncertainty and robustness characterization methods using probabilistic approach, randomized control analysis and design methods, some advanced nonlinear control techniques including bifurcation stabilization and compressor stabilization techniques, model reduction techniques, fault detection and fault tolerant control methods, and several robust stability analysis algorithms.

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1 Statement of the Problems Studied

The purpose of this research program is to study novel approaches to control oriented robust system identification and robust feedback control system design with Army problems, such as the vibration control of the gun turrets of M1A1 tanks, as application platforms. Because of the magnitudes of the loads exerted on military vehicles and weapon systems, and the need to reduce weight to augment performance and range, it is important to suppress vibration levels in components of deformable systems (such as unsteady or moving loads and vehicles, including large liquid containers, in motion over rough terrain), and to diminish the probability of system failure using suitable controllers. Specifically the gun turret of a M1A1 tank moving over rough terrain requires accurate pointing and tracking of the target that is crucial to the lethality of the weapon. As such, suppression of vibration via control methods is of primary importance in the design of such weapon systems. This means that the gun barrel cannot be treated as a rigid body and it must be treated as a flexible structure. It has been recognized that the vibration control of the gun turret is a challenging problem, particularly because it is very hard to obtain an accurate model for the structure and because of the inherited nonlinearities and infinite-dimensionality of the mechanical systems. Thus new ideas and approaches are being explored for modeling and control of flexible structures by this research program, aimed at applications to vibration control of the gun turrets of M1A1 tanks.

2 Summary of the Most Important Results

Our contribution includes the following several topics.

- Model Identification and Validation: We have developed some novel model identification and model validation techniques. In particular, we have developed an algorithm for modeling of normalized coprime factors with quantification of the identification error in L_∞ norm, which is particularly useful in modeling and control of flexible structures and yields good error response in terms of a measure similar to ν-gap, but without the constraint of the winding number. We have also done some further extension of the worst case H_∞ identification. We have also developed some model validation methods for both time and frequency domain data which can be applied in a general linear fractional transformation framework. See [1, 2, 3, 29, 30, 31].

- Probabilistic Robust Control: We have developed probabilistic approach to the characterization of model uncertainty and robustness. This approach has significant computational advantage and has the potential of reducing the conservativeness of the conventional methods. We have then explored the randomized algorithms in the evaluation of system robustness and the design of robust control systems. The motivation for this randomized approach comes from the fact that many deterministic worst-case robust analysis and synthesis problems are NP hard and may be quite conservative due to overbounding of the system uncertainties. An advantage of this randomized approach is that it has low computational complexity. In addition, the advantages of randomized algorithms can be found in the flexibility and adaptiveness in dealing with control analysis or synthesis problems with complicated constraints or in the situation of handling nonlinearities. These results are reported in [4, 5, 32, 33, 34].

- Nonlinear Control: We have developed a backstepping and augmentation method for robust stabilization and disturbance attenuation of several classes of MIMO nonlinear systems. We have also studied the problem of globally asymptotic stability in probability for a class of multi-input stochastic nonlinear systems. These results are reported in [6, 7, 35, 36, 37, 38].

- Bifurcation Control and its Applications in Compressor Stabilization: Control of compressor stall and surge is very important in Army and Air Force applications. We have developed a series techniques using bifurcation control theory. Results are compared with different types of control techniques. The results are shown to be quite effective in the stabilization of compressor instability. One of the advantage of our methods is the computability. These results are reported in [8, 9, 10, 11, 12, 14, 13, 39, 40, 41, 42, 43, 44, 45, 46, 47].

- Model Reduction: We have proposed a new balanced realization and model reduction method for possibly unstable systems by introducing some new controllability and observability Gramians. We have also shown that the design of a reduced order optimal H_2 filter is equivalent to a frequency weighted L_2 norm model reduction problem. Connections between relative model reduction and the robustness with the gap metric uncertainty are also established. See [15, 16, 48, 17].

- Fault Diagnosis and Fault Tolerant Control: We have proposed a new controller architecture that can be used for fault tolerant control and promises to overcome the conflict between the robustness and performance in the traditional feedback framework. We believe that this is a major breakthrough in modern feedback control technology. We have also made progress in fault detection and diagnosis based on hidden Markov chain model. This approach provides an integrated framework for fault detection, diagnosis, and state estimation. It is able to detect and isolate multiple faults substantially more quickly and more reliably than many existing approaches. Moreover, We have made progress in developing a fault tolerant and reconfigurable control methodology. We have proposed a reconfigurability criterion and a method for estimating the control effectiveness. See [18, 19, 49, 20, 50, 51, 52, 53].

- Robust Stability and Control of Uncertain Systems: We have derived several the least conservative stability conditions for uncertain time delay system. We have proposed an effective numerical solution to the robust $\mathcal{D}$-stability margin problem under polynomic structured real parametric uncertainty and developed a parallel frequency sweeping algorithm for computing the maximal structured singular value μ without tightly bounding μ for each frequency and thus significantly reduce the computational complexity. We have also developed some parametric H_∞ loopshaping techniques and made the H_∞ control theory more accessible to students. Finally, we have developed design techniques for multiobjective filtering and control problems. These results are reported in [21, 22, 54, 23, 24, 55, 56, 57, 58, 59, 60, 25].

- Filter Design: We have proposed several QMF banks design methods. See [26, 27, 28].

3 List of Publications

Journal Publications

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4 Scientific Personnel

The following personnel were supported partially by this project and the matching fund from the Board of Regents of the State of Louisiana:

- PI, Professor Kemin Zhou
- Co-PI, Professor Guoxiang Gu
- Graduate Assistants: Calin Belta, Danial U. Campos-Delgado, Xiang Chen, Xinjia Chen, Zhen Ding, Jian Huang, Yun-Ping Huang, P. Martin, A. Medina, Aravind Pamula, Jagadeesh Sankaran, H. Song.
- Research Fellows: Dr. Xiaoping Liu, Dr. Youmin Zheng, and Dr. Zhang Ren (all supported by a matching fund from the state)

The following students received MS degrees during this period:

- Calin Belta, M.S., Stability Analysis of Axial Flow Compressors, May 1999.
- Danial U. Campos-Delgado, MS, (nonthesis) May 1999.
- Xinjia Chen, MS, On the Probabilistic Characterization of Model Uncertainty and Robustness, April 1997.
- Zhen Ding, MS, (nonthesis) Robust Control of a Micropositioner, December 1998.

- Merten Jung, M.S., Control of a Single Flexible Link, July 1998. (This student was supported by a scholarship).
- Ana Karina Medina, M.S., Robustness of Feedback Control for Compression Systems, May 1999.
- Jagadeesh Sankaran, MS, DSP Based Digital Controller for an AMB Dynamic Absorber, December 1997.

The following students received PhD degrees during this period:

- Xiang Chen, Ph.D., Multiobjective Optimal Filtering and Control, August 1998.
- Xinjia Chen, Ph.D., Probabilistic and Deterministic Algorithms for Information and Dynamic Systems, December 1999.
- Jian Huang, Ph.D., A System Approach to the Design of Multirate Filter Bank, July 1998.